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ABSTRACT

A search has been made for direct photon production in pBe interactions at 200 and 300 GeV/c over the kinematic region $1.5 < P_{\perp} < 4.0$ GeV/c and $-0.7 < X_F < 0.$ ($90^{\circ} < \theta_{cms} < 160^{\circ}$). An excess of single photons above that which is predicted from the measured π^{o} and η^{o} production is observed. The ratio of γ/π^{o} production is calculated assuming that the excess arises from direct photon production. We find that this ratio averages 0.070 ± 0.025 (including systematic errors) in this region of X_F and $P_{\perp}$ for our 200 and 300 GeV/c data. We have used our measured value of the η/π^{o} ratio of 0.47 ± 0.10 in the determination of the γ/π^{o} ratio. The variation of γ/π^{o} with X_F, $P_{\perp}$, X_R and θ_{cms} is presented.

Recently much speculation[1-7] has centered around the possibility of copious production of direct photons in hadronic collisions either by QCD or CIM mechanisms. Since the direct photons are a primary product of these interactions while the inclusive π°s are supposedly the result of quark fragmentation, the directly produced photon flux is expected to become comparable to the π° flux (in spite of the suppression by α) at high $P_\perp$. This paper reports on a search for direct photon production in pBe collisions at 200 and 300 GeV/c performed using the halo-free proton beam[8] in the Proton-West Area at Fermi National Accelerator Laboratory.

We have reported previously[9] the measurement of inclusive π° production over a large region of $X_\perp$ and X_F in the same double arm lead glass spectrometer used in this experiment. This apparatus is shown in Fig. 1. Along with the π° photon pairs, single photons which had energies above the trigger threshold and which were not accompanied by charged particles were recorded. This "single photon" flux arose from three main sources:

1. Single photons from inclusive π° and η° production where only one of the two decay photons is within the acceptance of the spectrometer arm.
2. High energy π° events in which the two decay photons coalesce into a single energy deposit in the lead glass array.
3. Neutral hadrons which produce single photon-like signals in the detectors.

Other sources of physics background such as ω°, η', or hyperon decay have been considered and are negligible compared to the above sources of the single photon signal.

In order to predict the level of the observed single photon signal, measurements were made of:

1. The neutral hadron to single photon ratio over a large range of X_F and $P_\perp$.
2. The ratio of η°/π° production over a much smaller range of X_F.
3. The π° inclusive spectra over a large range of X_F and $P_\perp$.

The measurement of the neutral hadrons was accomplished by inserting 11.3 radiation lengths of lead in front of the sweeping magnets of both arms in order to eliminate photons. The trigger for these special runs was the same as the trigger for the photon and π° data, namely the requirement of a neutral event imposed by the lucite hodoscopes and the presence of an energy deposit above trigger threshold in the lead glass array. The correction for the attenuation of neutral hadrons was calculated by using an effective interaction probability of 31% derived from measured total cross sections[10] on lead. The ratio of neutral hadrons which trigger the apparatus to the single photon signal varies with $P_\perp$ and X_F from the 10% level at low $P_\perp$ and X_F to the 30% level at the edges of the kinematic region investigated in this search.

The measurement of η^o/π^o in this experiment confirms previous experiments[11-14] which have detected copious production of η^o in pp collisions. We have analyzed data taken at the smallest laboratory angle settings of the spectrometer arms where there is some acceptance for η^o and have detected the two photons from η^o decay. These data are shown in Fig. 2. After corrections for the relative acceptance and the $\eta \rightarrow \gamma\gamma$ branching ratio, the production ratio is determined to be $\eta^o/\pi^o = 0.47 \pm 0.10$ in the range $2.5 < P_\perp < 5$ GeV/c. These data are consistent with this ratio being independent of $P_\perp$ and $\sqrt{s}$. The other measurement[14] of η^o/π^o performed at Fermilab energies yielded a result 0.43 ± 0.10. The ISR measurements[11-13] are slightly higher (of order 0.50 - 0.55) but are still consistent with our measurement within the assigned errors. For the determination of the direct photon signal a value of 0.55 has been used in order not to underestimate the contribution of η photons to the observed single photon signal. The assumption has been made that this ratio is independent of $P_\perp$ and X_F. This assumption is consistent with all existing data.

Finally we have detected both photons from π^o decay, reconstructed the π^o mass spectrum assuming all interactions take place in the thin (34 mil) Be target (target out rates are much less than .1% of target in rates in the halo free beam), and determined the π^o cross section over a large range of $P_\perp$ and X_F. The two photon backgrounds under the π^o peak have been subtracted and the number of observed π^o's has been determined in each $P_\perp$ and X_F bin. The conversion probability for single photons in the spectrometer arms has been determined from the π^o photons to be $0.16 \pm .02$ independent of photon energy. This probability has been used to correct the data for loss of π^0 events relative to single photons due to the vetoing of converting events by the hodoscope requirements.

The inclusive π° data have been fit as a function of $P_\perp$ and X_R and the resultant fit has been used as input to a detailed Monte Carlo which generates π°'s and η°'s in the appropriate ratios with the observed distribution. (The coalescing events in the π° Monte Carlo have been corrected to take into account the conversion probability of either photon.) The shower patterns of the one and two photon events in the lead glass arrays have been generated using measured energy sharing distributions in the 2½" x 2½" elements. These shower sharing patterns, originally determined using shower calculations[15], were slightly modified to agree with energy sharing patterns measured in the detector using 4, 8, 16, and 32 GeV/c electrons from a calibration beam[16]. Detailed scans of the elements of these arrays were performed in situ, measuring the sharing of the shower in 0.1 inch steps.

The energies generated in individual counters by the Monte Carlo were further modified to take into account ADC digitization and energy fluctuations (as predicted by oberved single counter resolutions). These Monte Carlo events were then analyzed using the same photon pattern recognition, energy recombination, and position reconstruction techniques[17] as were used in analyzing the data. For each angle and energy of either spectrometer arm, η° and π° Monte Carlo calculations incorporating all of these features were performed.

These Monte Carlos were used to calculate the expected number of single photon-like events. Explicitly the ratio of direct gamma to π° invariant cross section in any particular X_F and $P_\perp$ bin is given by

$$\frac{\gamma}{\pi^\circ} = \frac{\varepsilon(\pi^\circ)}{\varepsilon(\gamma)} \cdot \frac{N_\gamma - N_\gamma^{MC}}{N_{\pi^\circ}} \qquad (1)$$

where N_γ = Number of observed photons (neutral hadrons subtracted).

N_{π° = Number of observed π° (background two photon combinations subtracted).

N_γ^{MC} = Number of predicted single photon-like events.

$= N_{\eta\to\gamma} + N_{\pi^\circ\to\gamma} + N_{\text{coalescing } \pi^\circ}$.

$\varepsilon(\pi^\circ)$ = Acceptance of the spectrometer arms as a function of X_F and $P_\perp$ for π° events.

$\varepsilon(\gamma)$ = Acceptance of the spectrometer arms as a function of X_F and $P_\perp$ for <u>direct</u> γ.

with

$$N_\gamma^{MC} = W_\gamma^{MC} \cdot \left(\frac{N_{\pi^\circ}}{W_{\pi^\circ}^{MC}}\right)_{\text{normalization region}} \qquad (2)$$

W_γ^{MC} = Monte Carlo weight of accepted single photon-like events predicted from the three sources.

$\left(\frac{N_{\pi^\circ}}{W_{\pi^\circ}^{MC}}\right)_{\text{normalization region}}$ = Ratio of the number of observed pizero's in a given normalization region to the Monte Carlo calculated weight of the accepted π° events predicted in the normalization region.

As can be seen from Eq. (2) the number of single photons predicted in a given X_F and $P_\perp$ bin is normalized to the number of π°'s observed in a given normalization region. The choice of the normalization region can vary from one which includes the entire acceptance of a spectrometer arm to a region which is identical to the bin of X_F and $P_\perp$ for which the ratio of γ/π° is calculated (X_F bins = .02, $P_\perp$ bins = .25 GeV/c). The two extremes have been tried and the values of γ/π° determined by both methods are consistent within errors. The results quoted are determined choosing the normalization region to be the same X_F and $P_\perp$ bin for which the γ/π° ratio is calculated. A minimum level of π° statistics in the bin was required ($N_{\pi^\circ} \sim 5$) before that bin is included in the results. The "local" normalization was chosen to make the final result less sensitive to any details of disagreement between the Monte Carlo π° distribution and the π° data. Finally, the choice of local normalization is less sensitive to difficulties in calculating acceptances near the edges of the aperture. In Fig. 3 we show examples of the X_F and $P_\perp$ projections of the data and the predicted contributions to the single photon spectrum for a particular spectrometer angle and energy.

A number of possible sources of systematic problems have been studied to see what effect they have on the γ/π° ratio. The most serious of these are:

1. Determination of the number of π° events. The subtraction of the background of uncorrelated

two photon events under the π^0 peak is the major uncertainty in estimating the number of π^0's.

2. Shifts of the energy scale of the single photon events relative to the pizero events because of non-linearity of the detector or because of reconstruction of π^0 or single photon energies.
3. Differences in the X_F and $P_\perp$ distributions of π^0 events between data and the Monte Carlo.
4. Differences in the results of the pattern recognition techniques when applied to one and two photon showers in the Monte Carlo and the data.
5. Error in the η/π^0 ratio.
6. Error in the conversion probability for photons in the charged particle counters in the spectrometer arms.

We have estimated the systematic error due to 1) by using several fitting techniques and several background shapes which vary within a reasonable range. The error in the determination of the number of π^0's for the various runs was typically ±5%. This leads to an error of less than ±.016 in the final γ/π^0 ratio.

Secondly, systematic errors which arise from possible nonlinearities of the lead glass detector were investigated by comparing the lead glass pulse heights to the energy of the calibration electron beam as determined both from the beam transport magnet settings and from the PWC momentum measurement to be less than 0.5% up to 30 GeV/c. This source was determined to make less than ±.007 error in the γ/π^o ratio due to systematic shifts of the π^o energy spectrum. In addition, reconstruction of the single photon and two photon events in the Monte Carlo and data were performed using the same software with the exception of corrections to account for unseen energy of the photons which convert in the 1.13 radiation length of lead converter in front of the glass arrays. This energy correction was determined from measurements of the correlation of $\frac{dE}{dX}$ (as observed in the S1·S2 counters between the lead converter and the lead glass arrays) with energy shifts of the calibration electron beam peak. We estimate the error in the γ/π^o induced by relative systematic shifts of reconstructed single photon and π^o energy spectra due to this source to be less than +.007/-.016.

Thirdly, we have estimated the reasonable limits for systematic changes in γ/π^o arising from differences between the π^o Monte Carlo and the π^o inclusive data by calculating the γ/π^o ratio varying the Monte Carlo form of the π^o inclusive cross section. We have taken $(E\, d\sigma/dp^3)_{\pi^o} \sim (1-X_R)^M\, P_\perp^{-N}$ and have varied M and N from the fitted values. The estimated systematic error in γ/π^o due to reasonable variations in the Monte Carlo was less than +.018/-.004. For this analysis we have used the flattest $P_\perp$ dependence (N=8) which is still consistent with our data.

We have investigated possible problems in the pattern recognition techniques which were applied to the Monte Carlo and data. Low level counter noise has been extracted from the data by examining the non-trigger arm in inclusive runs and these random low energy fluctuations have been added to the Monte Carlo events to see if the ratio of single photons to recognized π^o events remained stable. As a second check of the stability of the γ/π^o ratio, we varied over a wide range the pattern recognition threshold parameters which determine how distinct the second (or lower energy) photon must be from the higher energy photon in order to be resolved. We estimate from these studies that the limit on the systematic error in the γ/π^o ratio due to the pattern recognition technique is +.01/-.01.

Finally in order to estimate the systematic error due to the error in the η/π^o ratio and the error in the conversion probability we have analyzed some of our data with different values of these parameters. We estimate that the systematic change in γ/π^o due to the error in the η/π^o ratio to be +.007/-.002. The error in the conversion probability could contribute a systematic shift of less than +.005/-.005 to the γ/π^o ratio.

Combining all of these effects together the total systematic error in the γ/π^o ratio was estimated to be $\pm$.025. As an additional check on the correctness of this estimate of systematic error both spectrometer arms have been analyzed separately. The source of systematic error due to 1, 3, and 4 are considerably different for the arms since the solid angle and the distance of the arrays from the target are different. The γ/π^0 ratios from the two arms are found to be consistent within the assigned errors.

In Fig. 4 the γ/π^0 ratio is shown as a function of $P_\perp$ and X_F for the 200 and 300 GeV/c data (error bars includes statistical error and the error on the background from neutral hadrons; the shaded regions indicate variations of levels consistent with the estimate of systematic errors). The same ratio is shown in Fig. 5 vs. X_R and θ_{cms}. Both distributions show an excess of single photons leading to a γ/π^0 ratio which seem to rise as X_F and/or $P_\perp$ increases. The level and dependence of γ/π^0 on X_R and $P_\perp$ appears to be the same for data taken at both energies. According to Refs. 3-5 a direct photon production should be dominated by the Compton scattering of a gluon (QCD) or a $q\bar{q}$ meson-like state (CIM) from a constituent quark with the scattered object materializing as a final state real photon. We have shown in Figs. 4 and 5 the direct photon prediction of Brodsky et al[3] which contains both CIM and QCD and is divided by the comparable CIM and QCD prediction of π^0 production. In addition, we have shown separately the QCD and QCD + CIM prediction of Halzen and Scott[18] which are divided by observed π^0 cross sections and which have the direct photon production calculation normalized to the observed level of di-muon production[19].

We have compared our data (which is an average ratio for the angular region ($90^\circ < \theta_{cms} < 160^\circ$) with two previously published results[20-21] from the CERN ISR. The γ/π^0 ratios quoted in Ref. 20 are much larger than our results averaging .20 ± .06

for the region $3.0 < P_{\perp} < 4.0$ GeV/c for data taken at $\sqrt{S} = 45$ and 53 GeV. We observe 0.080 ± .025 and 0.094 ± .025 at $\sqrt{S} = 19.4$ and 23.8 GeV respectively in the same $P_{\perp}$ interval. The second experiment[21] which studied the e^+e^- mass spectrum of internally converted photons produced at $\sqrt{S} = 55$ GeV yield a result of .0055 ± .0092 in the $P_{\perp}$ region between 2 and 3 GeV/c. In this same region we observe a ratio of .070 ± .025 averaging our 200 and 300 GeV/c data for our angular range.

In conclusion, we have seen an excess of single photons above that which can be explained by π^0 and η^0 decays. When interpreted as direct photon production this excess yields values of the γ/π^0 ratio of 0.065 ± 0.025 and .076 ± .025 in the $P_{\perp}$ region between 1.5 and 4.0 GeV/c for the 200 and 300 GeV/c data. The data suggest that this signal is increasing with increasing $P_{\perp}$ and increasing X_F.

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REFERENCES

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[1]G. R. Farrar and S. C. Frautschi, Phys. Rev. Lett. 36, 1017 (1976).

[2]G. R. Farrar, Phys. Lett. 67B, 337 (1977).

[3]F. Halzen and D. M. Scott, Phys. Rev. Lett. 40, 1117 (1978).

[4]R. Rückl, S. J. Brodsky, and J. F. Gunion, Phys. Rev. 18, 2469 (1978).

[5]F. Halzen and D. M. Scott, Phys. Rev. 18, 3378 (1978).

[6]A. P. Contogouris and S. Padopoulos, M. Hongoh, Phys. Rev. Lett. 19, 2607 (1979).

[7]R. D. Field, CALT-68-688 preprint.

[8]B. Cox and C. T. Murphy, Nucl. Instr. and Meth., 136, 35 (1976).

[9]R. M. Baltrusaitis et al., Inclusive π^0 Production Over Large $X_\perp$ and X_F Ranges in 200, 300, and 400 GeV/c Proton-Beryllium Interactions, Fermilab-Pub., 79/37-Exp, submitted to Physical Rev. Letters.

[10]S. P. Denisov et al., Nucl. Phys. B61, 62 (1973).

[11]K. Eggert et al., Phys. Lett. 74B, 267 (1978).

[12]F. W. Büsser et al., Nucl. Phys. B106, 1 (1976).

[13]C. Kourkoumelis et al., CERN EP/79-30, (April, 1978).

[14]C. J. Donaldson et al., Phys. Rev. Lett. 40, 684 (1978).

[15]U. Völkel, DESY 67/16, (May, 1979).

[16]B. Cox et al., Fermilab Technical Memo No. TM-765 6038.00.

[17]R. M. Baltrusaitis et al., Position Determination of High Energy Photons in Lead Glass, submitted to the 1979 Nuclear Sciences Symposium, (IEEE).

[18]F. Halzen, D. Scott, Private Communication.

[19] J. K. Yoh et al., Physical Review Letters, 41, 684 (1978).

[20] P. Darriulat et al., Nucl. Phys. B110, 365 (1976).

[21] J. H. Cobb et al., Physics Letters 78B, 519 (1978).

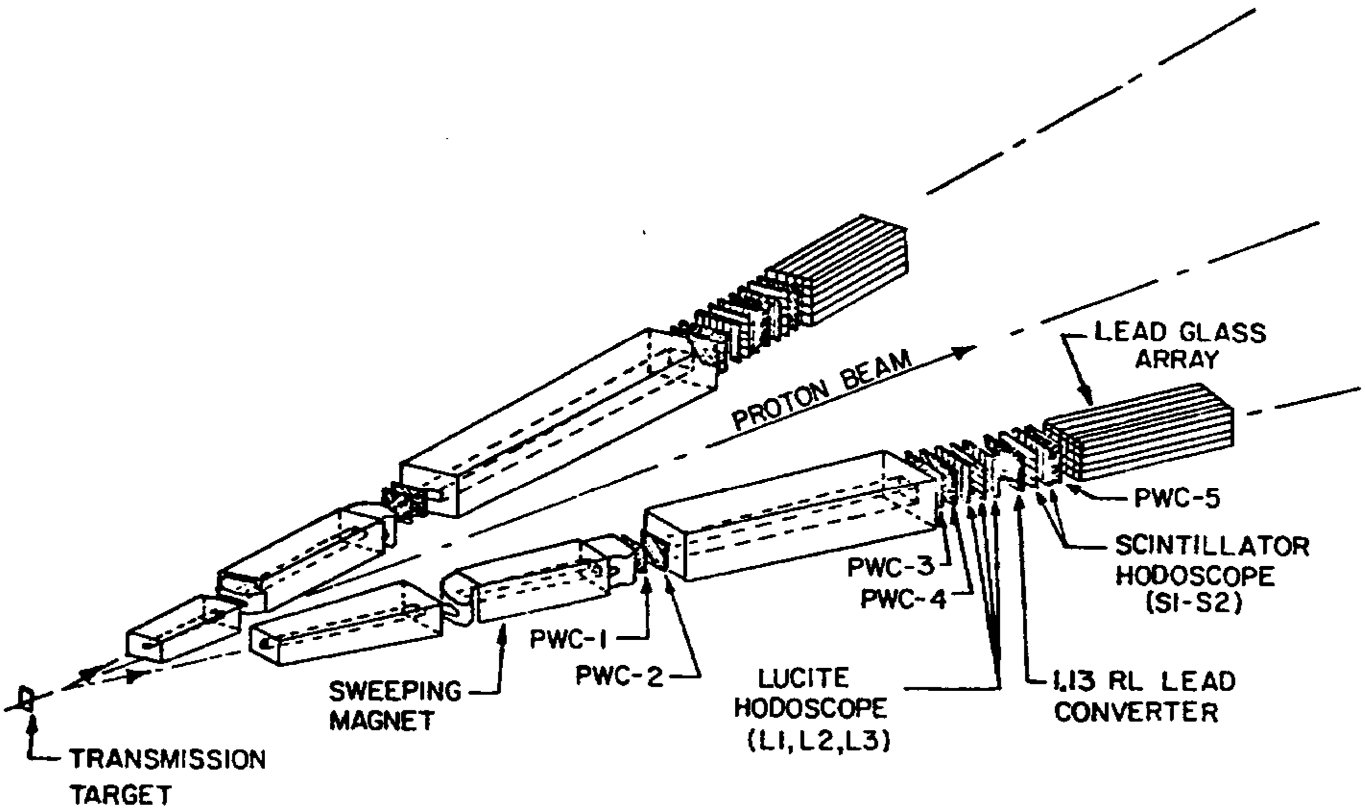


Fig. 1. Schematic view at the double-arm spectrometer.

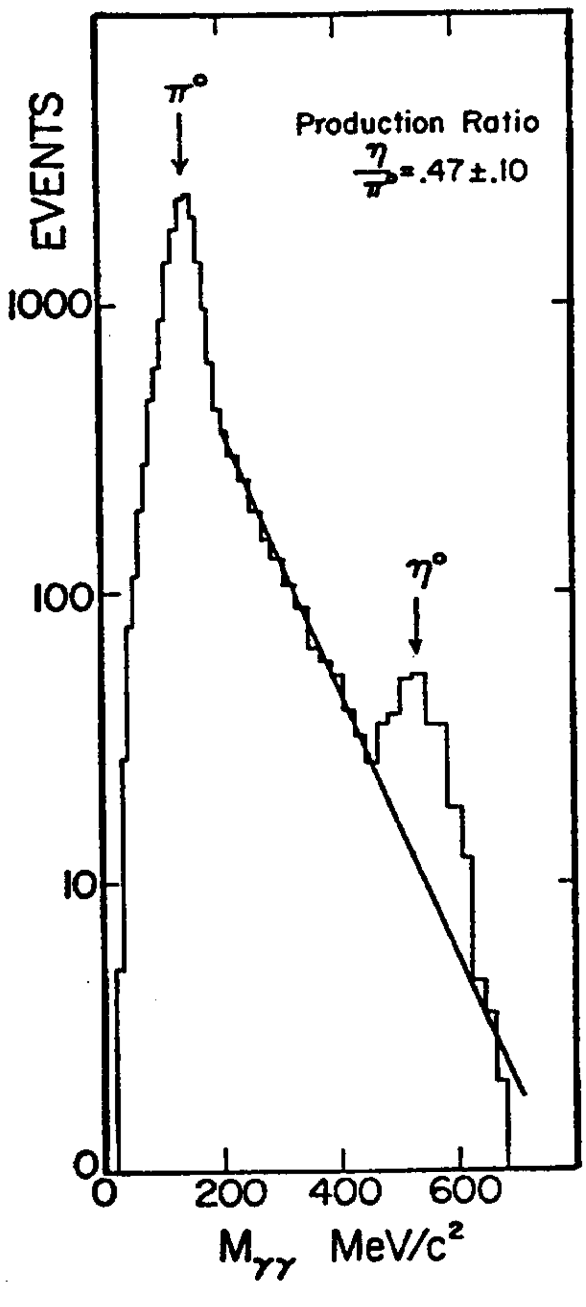


Fig. 2. Two photon mass distribution used in η^0 analysis.

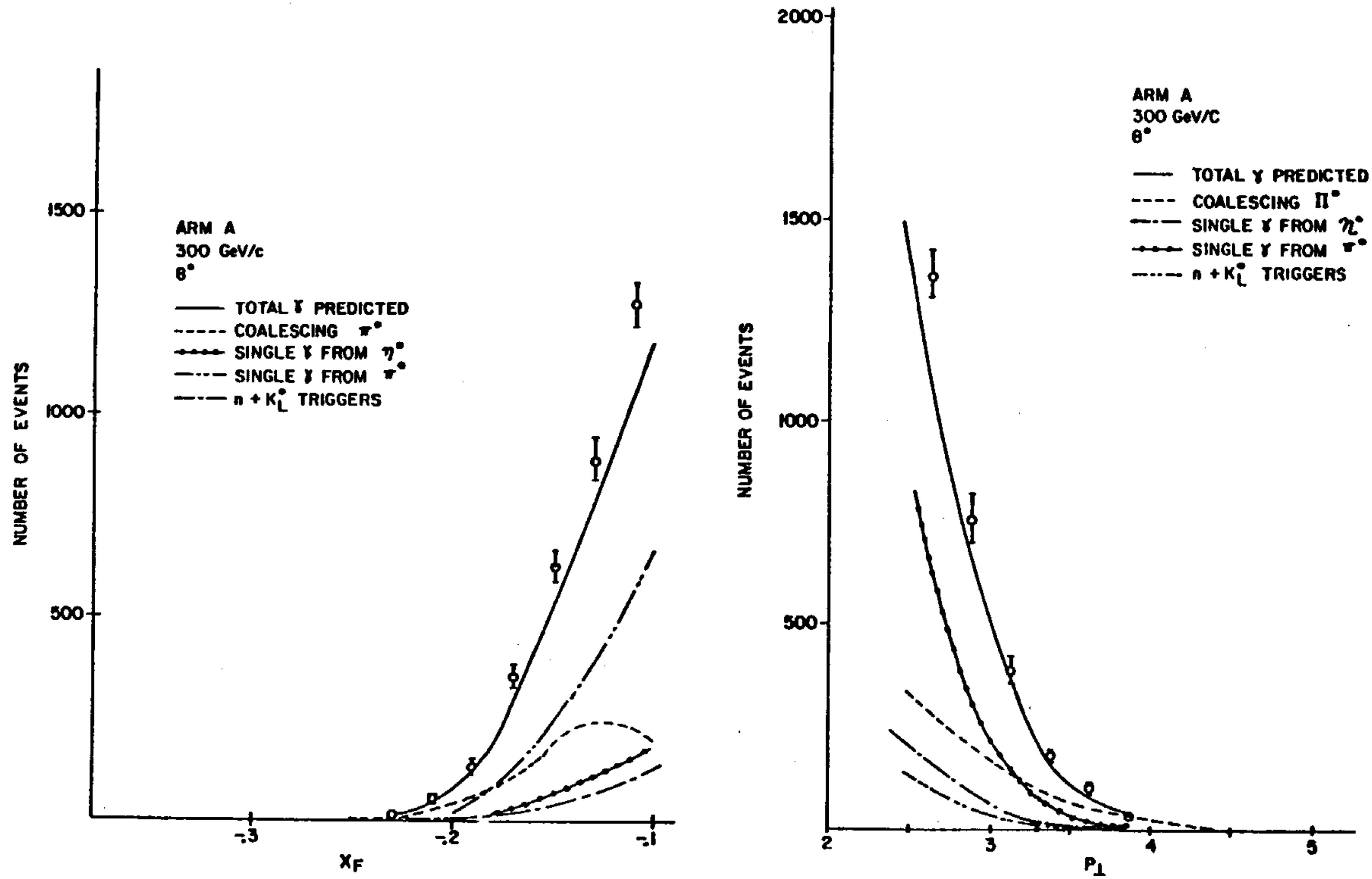
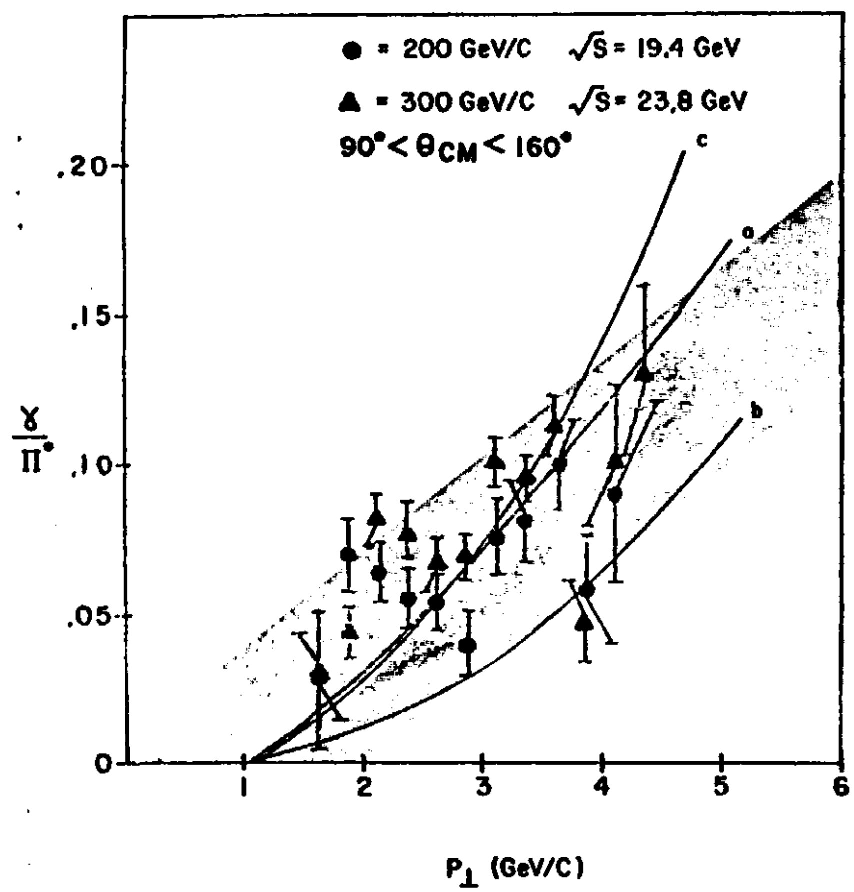
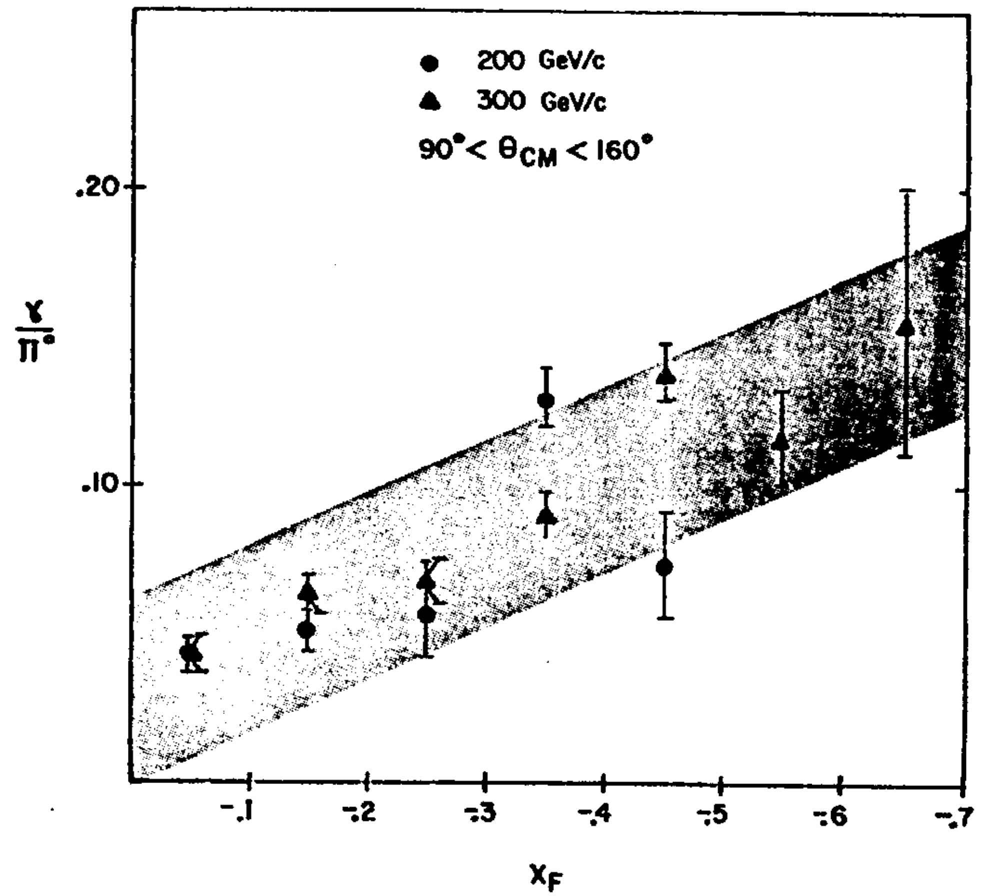


Fig. 3. Raw single photon-like spectra for the 300-GeV data taken with spectrometer arm A at 8° in the laboratory. Also shown are the various components of the predicted "single photon" spectrum.

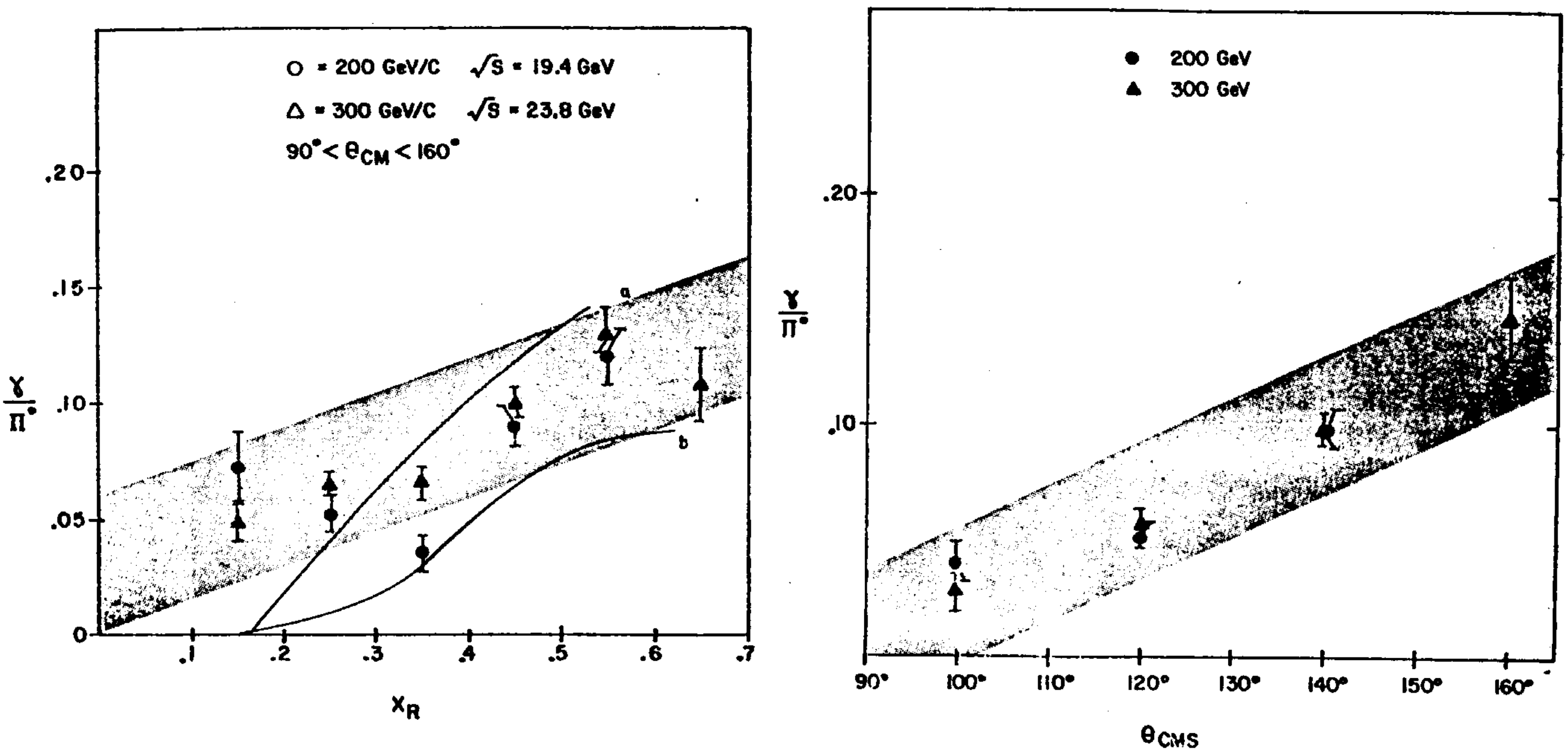


(a)



(b)

Fig. 4. The shaded bands indicate the magnitude of the systematic error. The level of the data may be shifted within the limit of the bands. a) γ/π^0 ratio vs. $P_\perp$ for 200 and 300 GeV pBe interactions; curve a is the prediction of Rückel, Brodsky and Gunion; curve b is the QCD calculation of Scott and Halzen, and curve c is the summed QCD + CIM calculation of Halzen and Scott. b) γ/π^0 ratio vs. X_F.



(a)

(b)

Fig. 5. a) γ/π^0 ratio vs. X_{Radial} for 200- and 300-GeV pBe interactions. Curve a is the prediction of Rückel, Brodsky, and Gunion for the X_R dependence of γ/π^0; curve b is the QCD prediction of Halzen and Scott. b) γ/π^0 ratio vs. θ_{cms}.